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A MEMS photoacoustic detector of terahertz radiation for chemical sensing

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Abstract

A piezoelectric Microelectromechanical system (MEMS) cantilever pressure sensor was designed, modeled, fabricated, and tested for sensing the photoacoustic response of gases to terahertz (THz) radiation. The sensing layers were comprised of three thin films; a lead zirconate titanate (PZT) piezoelectric layer sandwiched between two metal contact layers. The sensor materials were deposited on the silicon device layer of a silicon-on-insulator (SOI) wafer, which formed the physical structure of the cantilever. To release the cantilever, a hole was etched through the backside of the wafer and the buried oxide was removed with hydrofluoric acid. Devices were then tested in a custom made THz vacuum test chamber. Cantilever deflection was observed with a laser interferometer in the test chamber and preliminary data indicates the signals were caused by the photoacoustic effect. Future device data will also include the piezoelectric voltage signal analysis.

"Keywords: MEMS; Cantilever; Piezoelectric; Photoacoustic; Terahertz Sensor"

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1. Introduction

Many techniques have been employed over the last several decades for photoacoustic chemical sensing of trace gases and molecular analysis. Photoacoustic detection of radiation is an experimental technique widely used for molecular spectral detection in solids and gasses [1,2]. In this research, a MEMS cantilever was designed, modeled, fabricated, and tested in order to create a piezoelectric photoacoustic sensor responsive to a spectrum of sub-millimeter/terahertz radiation. The photoacoustic effect results

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when energy from an electromagnetic wave is absorbed by molecules and collisionally transferred though nonradiative pathways into translational energy. If the radiation produced by the source is properly modulated and enough of the energy is absorbed by a gaseous species, an acoustic wave results which can be detected by a pressure sensitive device. The novelty of this effort is the combination of four factors; acoustic cell size, the radiation source, the ability to collect displacement data from a MEMS cantilever transducer, and from a Michelson type interferometer. A finite element model of the cantilever is presented, followed by the fabrication process

2. Modeling and Cantilever Fabrication

Initial analytical design calculations similar to ones developed in [3] showed that a silicon cantilever 5x2x0.010 mm^3 (length x width x thickness) should produce the needed deflection to generate practical voltages from a piezoelectric layer. Modeling of the cantilever displacement over a range of applied pressures was performed in CoventorWare finite element software. Shown in Fig.3 is a model of a cantilever designed with the dimensions listed above and showed a tip deflection of 7.5 μm of for a 1 kPa applied load. Fine tuning of the model will be accomplished using interferometric and piezoelectric measurement data obtained in the acoustic test chamber. Additional modeling and testing will then be used to improve future cantilever design modifications.

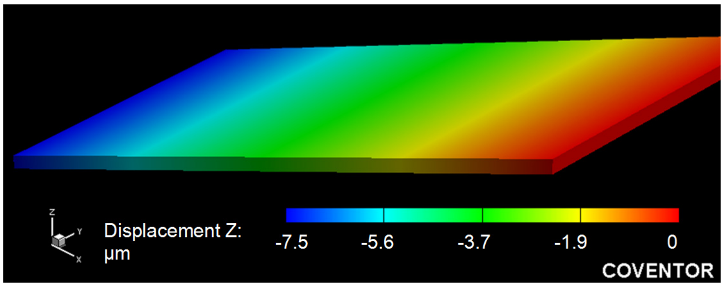


Fig. 3. CoventorWare finite element model of cantilever deflection for a static1kPa applied load.

Based on the modelled results, a cantilever design was designed and fabricated using MEMS fabrication processes. The piezoelectric cantilever fabrication process shown in Fig.1(A) began with the electron beam evaporation of a 2,500 Å film of silicon dioxide across the entire surface to provide electrical isolation from the silicon device layer. The oxide film was then annealed in a Solaris 150 rapid thermal annealing system for 3 min at 900 °C. Shown in Fig.1(B) is the deposition of the three thin films which form the upper/lower electrical contacts and PZT layer which were accomplished using standard photoresist patterning and liftoff techniques. For the lower metal contact layer, a Ti (250 Å) adhesion layer and Au (1,000 Å) layer were deposited via e-beam evaporation. Next a 2,000 Å piezoelectric layer of PZT was deposited in a RF sputtering system at 125 W, 5 mtorr, and yielded a 0.9 Å/sec deposition rate. The sputter target used had a composition of $PbZr_{0.52}Ti_{0.48}O_3$ and was selected in order to maximize the generated piezoelectric voltage signal. The top metal contact if Ti/Au was then deposited to complete the sensing layer on the device. Fig.1(C) illustrates the patterned DRIE etch of the device layer on the SOI wafer to define the cantilever shape and gap around the cantilever. The device layer was coated with a thick layer of resist to protect it during the latter fabrication steps. The backside of the wafer was then coated with SU-8 25 and exposed using a backside mask aligner. After the unexposed Su-8 was developed away, the sample was hard baked on a hotplate. Shown in Fig.1(D) is the sample after DRIE through the backside of the handle wafer down to the buried oxide, which also acted as an etch stop for the DRIE. The final steps of the fabrication process are shown in Fig.1(E) where the buried oxide is removed with hydrofluoric acid and the protective layer was removed from the device layer in a heated stripper solution.

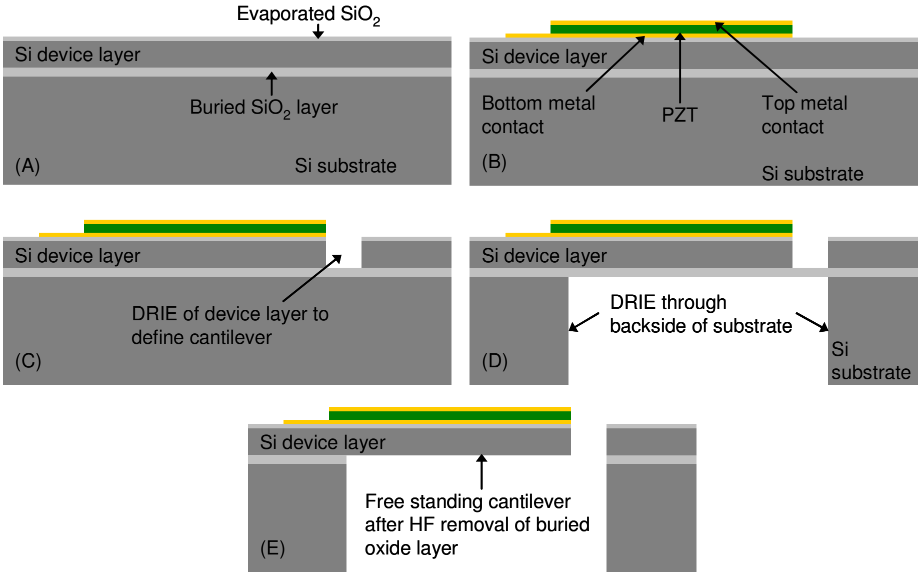
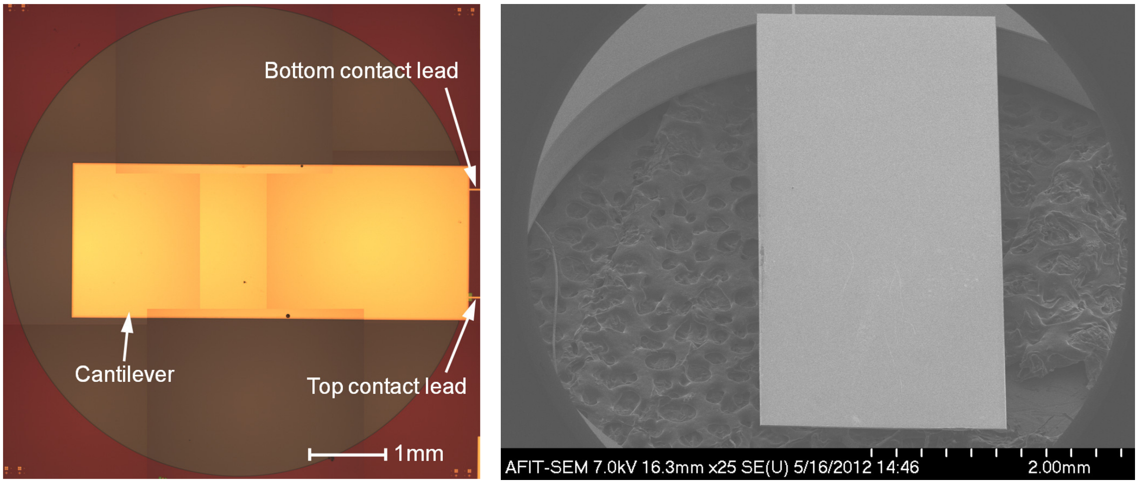


Fig. 1. Cantilever fabrication process, (A) deposit oxide layer, (B) deposit metal contacts and PZT, (C) etch device layer to form cantilever, (D) perform backside etch of handle wafer, and (E) remove oxide below cantilever.

A fabricated cantilever through the device layer etch step is shown in Fig.2(a) which has the oxide, metal contacts, and PZT layers. For baseline function tests of the acoustic chamber, some cantilever samples were made out of the silicone device layer only or with just the lower contact metal in place. Fig.2(b) is an SEM image of a released cantilever with only a lower contact metal layer deposited. The image was taken at a 45deg angle looking downward from the end of the cantilever tip.



(a) (b)

Fig. 2. (a) Cantilever with PZT and metal contacts before backside DRIE. (b) SEM of fully released cantilever with one metal contact layer.

3. Experimental Test Setup

The photoacoustic test chamber is designed to allow for both piezoelectric voltage signal and laser interferometer data measurements from cantilever deflection. Since the sensing element for the acoustic chamber is a MEMS cantilever; two types of cantilevers were initially fabricated in the device layer of a SOI wafer. The first samples made consisted of a bare silicone cantilever and later piezoelectric devices were made. Initially tests using a Michelson type laser interferometer were used to measure the deflection of a plain silicon cantilever. Preliminary results from the laser interferometer are promising but not yet complete. Data collection is triggered by the signal generator; electrical signals from the cantilever transducer and the laser interferometer will be synchronised. The piezoelectric samples have yet to be tested in the chamber.

The cylindrical acoustic absorption cell cavity is 2 inches long and has a 5 mm radius. Pressure in the chamber can be controlled over a wide range from low mtorr all the way up to atmospheric pressure. An advantage of this experimental setup is that the radiation source is capable of producing precise frequencies over a broad spectral range. Radiation source frequencies from 0.1-1 THz can be achieved. Radiation source modulation frequencies can be amplitude modulated on/off with a standard 50/50 duty cycle or operated in a duty cycle controlled mode where both the on and off durations can be specified. The duty cycle controlled mode is advantageous for testing these devices over different pressure ranges since the cantilever damping and deflection change with pressure.

4. Conclusions

In this effort a MEMS cantilever sensor was designed, modeled, fabricated, and preliminary photoacoustic data was collected with the laser interferometer configuration. The next phase will be to test the piezoelectric cantilever in the chamber and refine the mechanical design. The anticipated outcome of this research is photoacoustic detection that is independent of the absorption path length. This is a great advantage in comparison to traditional methods of detecting radiation and may lead to hand held THz chemical sensors and detector arrays for imaging.

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References

[1] G. West, J. Barrett, D. Siebert, et al. Photoacoustic spectroscopy, Review of Scientific Instruments, 54 (1983) 797-817.

[2] T. Kuusela, J. Kauppinen. *Photoacoustic Gas Analysis Using Interferometric Cantilever Microphone*, Applied Spectroscopy Reviews, 42 (2007) 443-474.

[3] J. Kauppinen, K. Wilcken, I. Kauppinen and V. Koskinen. *High sensitivity in gas analysis with photoacoustic detection*. Microchemical Journal 76(1–2), (2004) 151-159.